On the Design of LTCC Filter for Millimeter-Waves

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Abstract — **To test the repeatability of scattering parameters of LTCC bandpass filters at millimeter-waves a dual-mode stripline patch filter was designed. Measurement results showed 2.8 dB insertion loss and 12 dB return loss in passband. The measurements of two test structures exhibited good coincidence of scattering parameters, which are in a good agreement with the predicted results. To prevent the influence of the stripline package onto the filter performance additional investigations were carried out. As a result the suitable configuration of feed lines were chosen.**

I. Introduction

The low temperature co-fired ceramic (LTCC) technology is multi-layer thick film processing, which permits combining active and passive microwave components into monolithic module. This enables microwave devices to be fabricated with high overall reliability while keeping the cost competitively low. The impetuous development of local area networks (LAN) and car radar systems caused the intensive investigation of LTCC properties at microwaves and millimeter-waves. Many authors - to mention only a few of them [1,2] - report having tested different transmission lines (microstrip, stripline, coplanar, etc.) and passive components based on LTCC at frequencies up to 40GHz. These experiments show the capability of multi-layer LTCC technology to be utilized at millimeter-waves. However, fabrication tolerances of LTCC technology (currently it is possible to resolve 100μm/100μm line/space with 10% accuracy) strongly affect the repeatability of LTCC filter parameters. One way to avoid this problem is to design and manufacture a bandpass filter using thin film technology. Then it can be glued on top of the LTCC substrate [3]. Certainly, cost of such a hybrid structure significantly increases. It is better to find a suitable filter configuration satisfied LTCC technology requirements. On other hand, LTCC filters exhibit rather high attenuation in passband, which is caused by microwave loss of normal conductor due to skin effect. That is why extra attention has to be spent to select a correct structure with the highest Q-factor.

The paper reports the experimental investigations directed towards the study of the properties of dual-mode patch structure implemented in LTCC.

II. Filter Design

Fig.1 shows the conventional dual-mode resonant structure first reported in [4]. Such a structure has been developed from single-mode resonator (commonly used for microstrip patch antennas [5]) by adding a perturbation at a point that is 45 degrees from the axes of coupling to the resonator (the patch is cut in one of its corners). It enables two orthogonal modes, generated within the resonator, to be coupled.

The filters based on such a structure are supposed to posses the least sensitivity to the LTCC technology uncertainty. Each square patch replaces two commonly used half-wavelength resonators, the side of square patch being about half-wavelength. Thus, there are no narrow lines, the width of which is close to the technology limitations. Also these resonators are known to have advantageous features such as size compactness, low radiation loss, and easy-to-design layout.

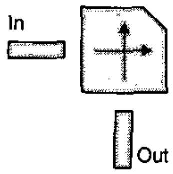

Fig. 1. The dual-mode resonant patch structure.

The aim of the design procedure is to build the filter with 2.1% bandwidth at 29 GHz and 12 dB return coefficient. To obtain the required, sufficiently strong coupling coefficient the resonant structure and feed lines were inserted into different metalization layers. So, the external coupling is realized by overlap between resonator and feed line and can easily be varied in accordance with design needs. By changing the depth of the cut the required coupling coefficient between generated modes can be achieved. It makes possible to design the second order filter.

Needles to say the filter operated at millimeter-waves should be inserted into a proper package in order to prevent radiation loss. It seems that the stripline filter realization is the most preferable solution. It enables us to design a package, where vertical walls are realized as closely situated vias (metalized holes).

The filter has been designed with the help of Ansoft Ensemble 8.0. To facilitate the execution of the design the filter housing was modeled as a cavity with ideal monolithic walls. The validity of this assumption is based on a fact that LTCC technology can resolve 200μm/200μm via/space. The estimation revealed that the distance between vias is 12 times less than the wavelength at the center frequency of the passband considered. The fact lead us to conclude that the package walls can be considered as monolithic ones.

III. Experimental Investigations

A. Filter Realization

This filter with central frequency of 29.1 GHz and 2.1 % passband utilized eight CT 2000 LTCC layers of 78 μm thickness with dielectric constant of 9.1. The length of the patch side was 1.5 mm. The widths of the input and output lines were 100 μm. The distance between the square patch and the feed lines was 156 μm and the feed lines overlapped the square patch by 500 μm. The area occupied by the proposed filter is 6×6 mm^2 in plane. The ground planes were printed on top and bottom of the substrate. The Ag conductors were screen-printed on unfired tape. All the layers were then laminated and co-fired.

B. Measurement Results

The wide band measurements of the dual-mode filter were performed. The comparison of the experimental and simulated characteristics of the filter is presented in Fig. 2. The return loss over the bandwidth is better than 12 dB. The structure reveals less than 2.8 dB loss in the passband.

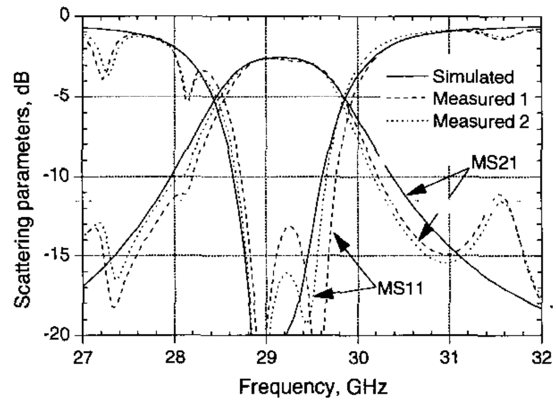

Fig. 2. The scattering parameters of the 2-pole LTCC filter.

As one can see the measured and predicted results coincide rather well in passband. However, additional resonances are observed in measured frequency band. We suppose they are caused by the filter package and this influence on the filter characteristics can be removed by changing the size or/and the configuration of the filter housing. The measurements of at least two test structures reveal good parameter repeatability of the filter. This allows concluding that the LTCC filter may find an application at millimeter-waves.

C. Estimation of unloaded Q-factor

Next point is the estimation of the unloaded Q-factor of the resonant structure involved. It gives a possibility to compare with convenient ones. If filter parameters are measured the unloaded Q-factor of the resonator can be expressed as follows:

$$Q_{unload} \approx \frac{4.343 \cdot n}{L_a \cdot \omega'}, \qquad (2)$$

where L_a - the total losses in the passband, ω' - the relative passband, n - the order of the filter. The unloaded Q-factor of the dual mode structure involved is 150.

For comparison we designed and measured a microstrip ring resonator and a stripline half-wavelength resonator. The former one exhibited 100 and the latter one showed 115. Thus the dual mode resonant structure is a very attractive option.

D. On The Package Design

The measured results (Fig. 3) exhibited the generation of high order package resonances. It was estimated that the dominant electrical mode for the packages involved is about 11 GHz and there are high modes close to the band considered. They do not allow achieving required minimal losses in the stopband.

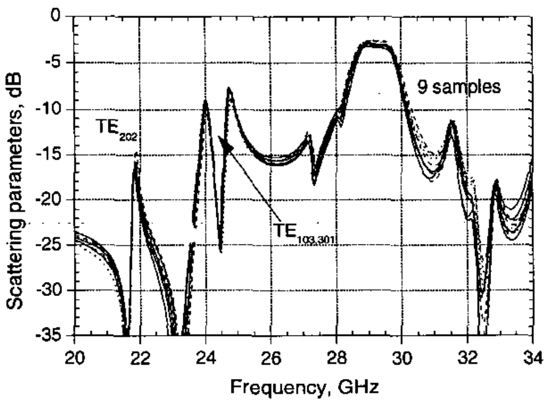

Fig. 3. The high order package resonances.

To prevent the influence of the package onto the filter performance its resonance frequencies must be far from the operating band. The best solution is to move all generated modes at frequencies higher than the filter passband.

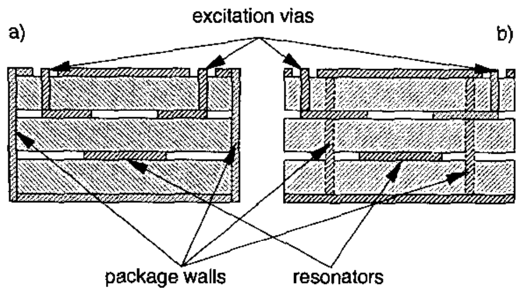

Fig. 4. The cross sectional view of the filter housing with excitation vias a) inside, b) outside housing.

Some investigation has been done in this direction. Fig. 4a) illustrates the filter feeding that was used. Such a realization provides the excitation of all electrical modes starting from the lowest one. The package size should be about 2×2 mm^2 in plane to shift the electrical dominant mode up to 35 GHz. However, walls close situated to the resonator will influence the filter characteristics. That leads to the filter design being more complicated.

Another way is to change the excitation of the filter as shown in Fig. 4b). In this case magnetic modes will be generated. It enables the first resonant mode to be removed up to 100 GHz. In addition to changing the way of excitation we have planed to decrease the amount of LTCC layers down to 4 (currently 8 layers). First of all it increases the lowest resonant frequency TM_{110}. Also it has some excellent consequences: easy to achieve better cooling and the device becomes cheaper. The redesign of the filter has been made and experimental investigation will be carried out in the nearest future.

IV. CONCLUSION

The LTCC dual mode bandpass filter has been designed and measured. The comparison of the predicted results and measured data shows good agreement. Also the repeatability of the scattering parameters of the LTCC filter was demonstrated. The investigation connected with the design of the filter package also has been carried out. The 2-pole filter satisfied our filter specification was redesigned in 4 layers and for new package configuration. It will be manufactured and measured soon.

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